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CORRELATION OF THE CENOZOIC THROUGH ITS MAMMALIAN LIFE

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XIII[1]

The sea borders of the United States may be correlated with each other and with those of Eurasia in Cenozoic times through their invertebrate life, but for the vast interior of the American continent we must depend chiefly upon the mammals and in a less degree upon the reptiles, fishes, insects, and plants. I foresee great aid through these latter sources, but it is clear that the mammals will always afford the chief means of correlation, since in all parts of Europe mammal-bearing formations alternate with marine shell-bearing formations.

The standard divisions of Cenozoic geologic time will always be those established in Europe. The problem set before the paleontologists of our country is therefore to compare and establish our time divisions as closely as possible with the European standards. For this reason since 1899 I have been pursuing an exact investigation of the sequence of mammalian life in America and in the European Tertiary formations, and have enlisted the co-operation of many European and American paleontologists in the hope that such precise data may be obtained as to secure common understanding and usage of chronologic terms in the two countries.

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[1] This article, which should have appeared as No. XIII in the series of correlation papers published last year, did not reach the *Journal of Geology* in time to be published in its proper place, in No. 7, 1909.

Previous to 1898 scattered attempts at the correlation of European horizons *inter se* were made by Dawkins, Schlosser, Osborn, Depéret, and others, but it was not until June, 1905, that there began in the *Comptes rendus* a remarkable series of papers by Depéret entitled "L'évolution des mammifères tertiaires," covering with fulness the whole subject of the succession of mammalian life in Europe, the correlation of all the known horizons, with theories as to the migrations between the continents of Eurasia, North America, and Africa. I am not in accord with Depéret on many of these theories but I accept in full his correlation of the mammal-bearing horizons on the continent, together with his subdivisions of geologic time.

Similarly in America there are the pioneer correlations of Leidy of the American formations with each other and with those of Europe, followed with increasing precision by those of Cope, Marsh, Scott, Clarke, Dall, and Osborn. In 1899 Matthew published *A Provisional Classification of the Freshwater Tertiary of the West*, and this together with his *Faunal Lists of the Tertiary Mammalia of the West*, published in 1909, afforded the American bases for Osborn's *Cenozoic Mammal Horizons of Western North America*, published in 1909, in which for the first time the succession of the mammalian life of the New and Old Worlds is closely compared.

In the meantime increasingly accurate field methods, especially in the horizontal recording of levels after methods introduced by Osborn, Hatcher, and Wortman, have resulted in the subdivision of the old "formations" of Leidy, Cope, and Marsh into successive *Life-zones* similar to those long in use in invertebrate paleontology. These life-zones are obviously as important in questions of time as they are in questions of phylogeny or descent; they narrow down the old correlation standard of the comparison of similar specific and generic stages to different levels; they add greatly to the possibilities of precise comparison in respect to the newer data of correlation, such as detailed evolution of related forms, the simultaneous introduction of new forms by migration, the predominance or abundance of certain forms, the convergence and divergence of American and European faunas.

Putting together all these facts of various kinds, the first result is the proof that the mammalian life of Eurasia and America in Tertiary times passed through a series of grand phases of union, of divergence, of reunion, and perhaps again of divergence. There are seven of these phases.

In the *first*, in Basal Eocene times, we find North America, Europe, and possibly South America peopled with archaic mammals of Mesozoic ancestry.

In the *second* faunal phase, of Lower Eocene times, we observe the first modernization, which occurs simultaneously in Europe and North America, by the invasion of many modern families of mammals, which intermingled with the archaic; the life of Europe and North America continues to be very similar.

In the *third* faunal phase, beginning in Middle Eocene times, the mammals of America and Europe gradually diverge and undergo an independent evolution with little or no faunal interchange; at the close of the Eocene the two faunas are very far apart.

In the *fourth* faunal phase, beginning in Lower Oligocene times, there is a sudden reunion of New and Old World life. At the same time there occurs in both countries a second very surprising modernization apparently by the further invasion of modern forms from the north.

A *fifth* faunal phase occurs in the Middle Miocene, when there is a fresh reunion in the New and Old Worlds by the arrival in America of the proboscideans and the short-limbed rhinoceroses.

Then follows a long period of independent evolution in the two countries until in the Middle Pliocene we enter a *sixth* faunal phase, in which a close land connection with South America is re-established, after an interval of separation reaching back into Eocene times.

Finally a *seventh* faunal phase occurs in Pleistocene or Glacial times, when all the larger North American mammals become extinct, as well as the south American invading stocks, while North America is replenished by a large fauna from Eurasia.

It will be noticed that these phases are in no way coincident either with the greater or with the lesser time divisions, for the obvious reason that these time divisions have all been established on the basis of the evolution of invertebrate life in Europe.

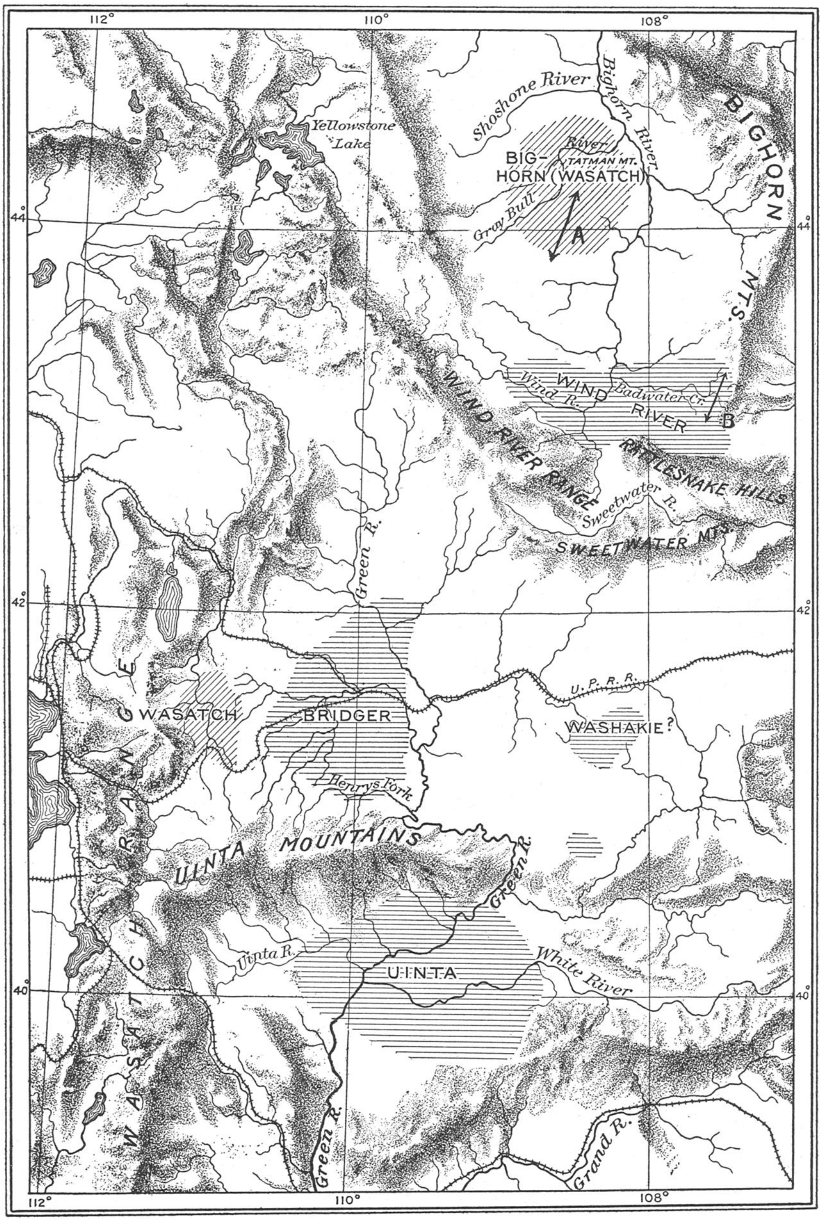

FIG. 1.—Map of southwestern Wyoming and northern Utah, showing partial areas of the Wasatch, Wind River, Bridger, and Uinta formations. Extensive areas of the Wasatch are purposely omitted. A, B, lines of sections by F. B. Loomis.

EOCENE

Basal.—The very opening of the Eocene furnishes one of the most brilliant examples of the possibilities of precise correlation through vertebrate life. Changes occurring in the interior of the American continent may be compared precisely with those along the northern coasts of France and Belgium. In each case great forms of reptilian life persist to the very close of the Cretaceous; the conditions of the American "Laramie," "Hell Creek," or Ceratops beds are similar to those of the Danian or Maestrichtian of Belgium; both mark the abrupt termination of the Age of Reptiles; both are overlaid by beds containing a number of very distinctive types of archaic mammals mingled with those of distinctive reptiles (*Champsosaurus*) found alike in the Puerco of Mexico, the Fort Union of Montana, the Thanetian of northern France. Thus we believe the opening of the Tertiary admits of close correlation in the Old and New Worlds. The succeeding rich Puerco-Torrejon mammalian life of New Mexico, so far as known, parallels that of the Thanetian (including the Cernaysian) stage of northwestern Europe. It is all *Paleocene,* or Basal Eocene.

Lower.—The beginning of the Lower Eocene is clearly defined in the Rocky Mountain region and with equal sharpness in northern France and Belgium by the appearance of *Coryphodon,* and by the opening of the second faunal phase with its advent of modernized life. Our Lower and Upper Wasatch correspond respectively with the Sparnacian and Ypresian stages of France. It is represented in deep and fairly rich exposures in northern New Mexico and in western, central, and northern Wyoming.

The Wind River of central Wyoming together with the Lower Huerfano near the Spanish Peaks of Colorado marks the upper life-zone of *Coryphodon* and may prove to correspond closely with the Ypresian of France. In the Rocky Mountains the Wind River is readily distinguished by the survival of a number of characteristic Lower Eocene types (*Coryphodon, Phenacodus*) and the fresh arrival of a number of equally characteristic Middle Eocene types (uintatheres, titanotheres). It is consequently an ideal transition fauna. Unfortunately the formations believed to be of corresponding age in France are poor in mammal remains.

From this time on to the summit of the Eocene we are passing into the third faunal phase, or divergence and independent evolution of the life of Europe and America. Consequently close correlation is almost impossible; at no period in the Tertiary were the Nearctic and Palearctic faunas so widely separated.

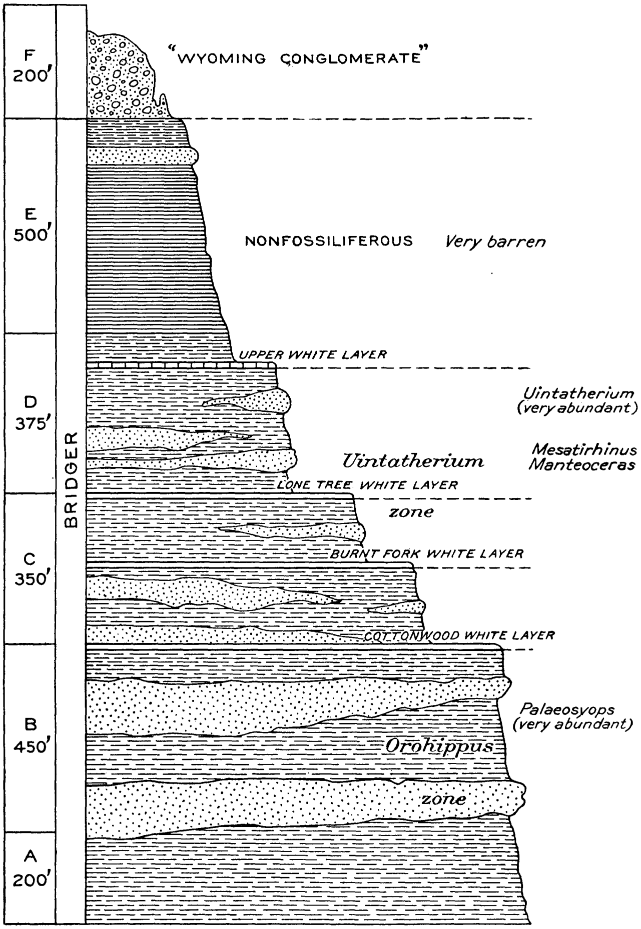

FIG. 2.—Columnar section of the Bridger formation, Henrys Fork, western Wyoming. After studies by Matthew and Granger, 1902.

Middle.—With the American Bridger, 1,800 feet in thickness, we enter the Middle Eocene and broadly compare the Lower Bridger with the Lutetian and the Upper Bridger with the Bartonian of France. The precise survey of the life-zones of the Bridger by Granger and Matthew marks one of the greatest advances of recent times.

Similarly under the direction of the present writer the Washakie of central Wyoming has been surveyed precisely by Granger, proving that the Lower Washakie is identical in age and in its mammalian life with the Upper Bridger and broadly corresponds with the Bartonian, or closing stage of the Middle Eocene of France. We are now in the Uintatherium Zone, all the famous discoveries of Cope and

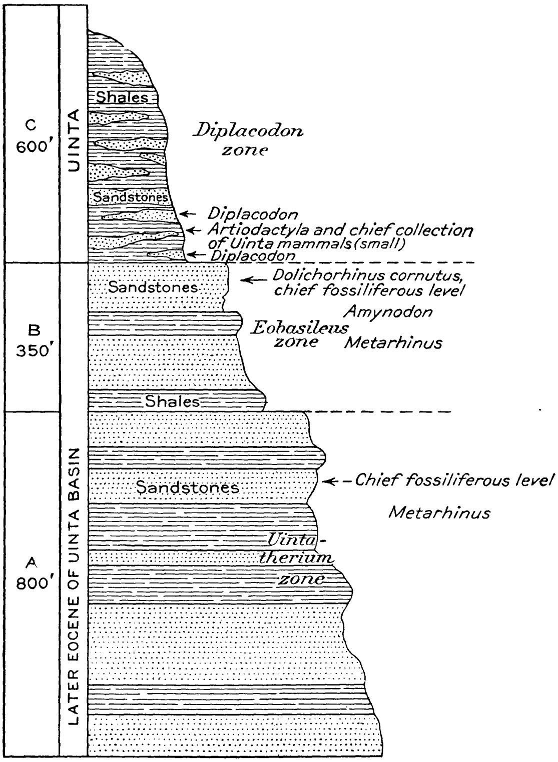
C
600′
UINTA
Shales
Diplacodon
zone
Sandstones
Diplacodon
Artiodactyla and chief collection of Uinta mammals (small)
Diplacodon
B
350′
Sandstones
Dolichorhinus cornutus, chief fossiliferous level
Amynodon
Eobasileus
zone
Metarhinus
Shales
A
800′
LATER EOCENE OF UINTA BASIN
Sandstones
Chief fossiliferous level
Metarhinus
Uinta-
therium
zone

FIG. 3.—Columnar section of the Uinta formation, northern Utah. In A and B the diagram does not properly represent the irregular nature of the so-called sandstones and clays, which are probably in part coarser and finer volcanic-dust deposits. Modified from notes by O. A. Peterson, 1894. Faunistic studies of Osborn.

Marsh having been made at this level. Here belongs also the beginning of the Uinta deposition of northern Utah.

We now pass into the Eobasileus Zone of the Upper Washakie and the Middle Uinta, in which the long-headed uintatheres described by Cope as *Eobasileus* and *Loxolophodon* occur mingled with remains of highly specialized Eocene titanotheres. This is apparently the lower level of the Upper Eocene and is broadly comparable with the Ludian stage of France.

Upper.—The succeeding Ligurian stage of France may be paralleled with the upper, or true Uinta, the Diplacodon Zone of Marsh. The zonal type is a large titanothere with well-developed bony horns, transitional in many characters to the Lower Oligocene titanotheres; in fact, the summit of the thick Diplacodon Zone of 600 feet will probably prove to coincide with the base of the White River Group on the great plains. Quite recently, during the summer of 1909, the much-desired sequence of Oligocence and Eocene strata was discovered by Mr. Granger of the American Museum expedition. The Diplacodon Zone has been discovered in the Wind River region of Wyoming underlying the Titanotherium Zone.

The Ligurian stage of France is that of the famous Gypse de Montmartre discovered by Cuvier, full of paleotheres and anoplotheres, a mammal fauna totally distinct from that of the Rocky Mountain region.

OLIGOCENE

Lower.—The Oligocene opens in the New and Old Worlds with the fourth faunal phase and second modernization, which since it affects alike Europe and America probably indicates a fresh migration from the great unknown northern, or Holarctic region. With this migration close faunal resemblance is re-established with western Europe, and thereby comes a welcome means of geologic correlation; in other words, we may with considerable confidênce consider that the base of the White River group was nearly coincident with the inferior Tongrian of France. Sixteen new families of mammals appear in America, all of them still existing, and seventeen modern, or still existing, families appear in Europe. This momentous faunal change in North America is partly attributable to the fact that this is our first glimpse of the life of the Great Plains.

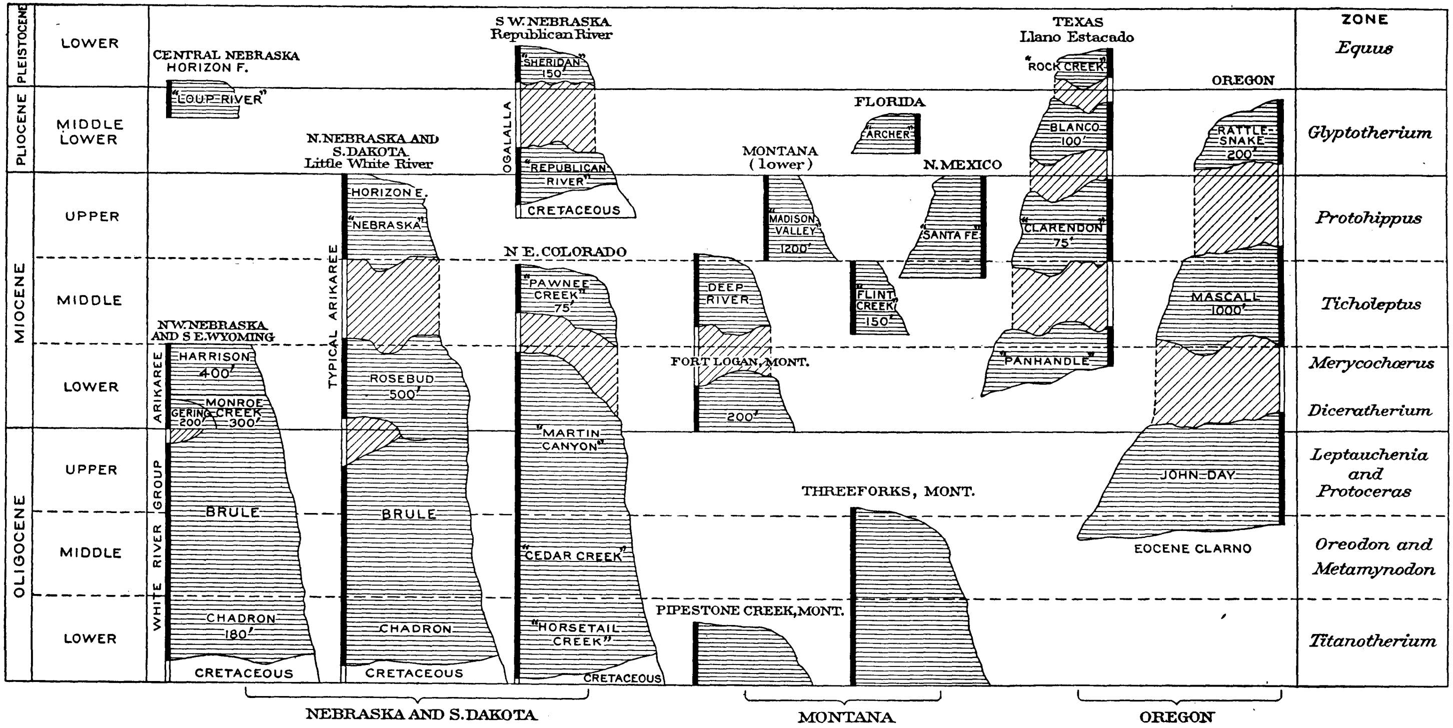

FIG. 4.—Provisional correlation of some of the chief epicontinental Oligocene-Pleistocene deposits and formations of the West in which fossil mammals have been recorded. Unlike the sections in the other figures, these sections are not represented to scale; they are purely conventional. After W. D. Matthew and H. F. Osborn, 1907.

Middle.—The Lower Oligocene, or Titanotherium Zone, most accurately surveyed by Hatcher, is succeeded by the Middle Oligocene or Oreodon Zone, broadly comparable with the Superior Tongrian and Stampian of France, both containing similar types of amphibious rhinoceroses and many other mammals. One of the chief points of interest here is the sharp separation discovered by Matthew between the plains-living mammals buried in the so-called clays, or finer deposits, and the forest-living mammals buried in the coarser intrusive river sandstones.

Upper.—The close of the Oligocene takes us into the John Day tuff deposits of Oregon, and is generally parallel with the Aquitanian Stage of France, typified by St. Gérand-le-Puy. It is the Diceratherium Zone, or the climax of the evolution of the pair-horned rhinoceroses in both countries. We pass also into the Upper Merycochoerus Zone at the summit of the John Day and at the base of the Arikaree formation extending along Pine Ridge of South Dakota. Here we are again in difficulty in determining just when the American Oligocene should be regarded as closing and the Miocene as beginning. An abundance of diceratheres and entelodonts still betokens Oligocene times, but it is possible that we may be in the Miocene. This is one of the doubtful points requiring further investigation.

MIOCENE

The solution of the Lower and Middle Miocene sequence in America through the discoveries of Hatcher, Peterson, and of Matthew marks another great advance of recent years.

Lower.—There is no question that in the Upper Arikaree, the Upper Harrison of Hatcher, and the Upper Rosebud of Matthew we are fairly in Lower Miocene times corresponding with the Burdigalian of Europe. There is now considerable faunal difference between the New and Old Worlds. The Proboscidea certainly enter Europe at this time, and one of the debated points is when they first appear in North America.

Middle.—The Vindobonian, or Middle Miocene of Europe, divided into the three successive stages of Sansan, Simorre, and St. Gaudens, is again with considerable confidence compared with the Deep River of Montana, and the Pawnee Buttes of Colorado, through the researches of Scott and Matthew. Here we enter the fifth faunal phase, marked by fresh migrations and the first undoubted appearance of the proboscideans and short-limbed rhinoceroses in America, both arrivals from the Old World. Physiographic changes are indicated in evidence of increasing summer droughts, numerical increase of animals adapted to plains-living and the semi-arid conditions, in the disappearance of most of the browsing types. The correlation is, however, by no means close at present, because the life of Europe and the great American plains is of different local habitat.

Upper.—In the Upper Miocene, however, we are again somewhat more confident in correlating our Hipparion and Procamelus Zone, the "Loup Fork" of early writers, with the Pontian or Pikermi stage of Europe typified by the wonderful advent of the plains fauna of Asia which spreads all over southern Europe, probably into Africa and the far East of southern Asia and China.

PLIOCENE

It is difficult again to demarkate the close of our Miocene and the beginning of our Pliocene. For the first time in American Tertiary history an invertebrate paleontologist (Dall) comes to our aid through discovering that the mammals of the Alachua Clays of Florida overlie certain true Lower Pliocene molluscs. The mammals of these clays are comparable to those of the Republican River of Kansas, and we are consequently disposed to place the latter in the Lower Pliocene. It is at least a more recent phase than the "Loup Fork," and is hence distinguished as the Peraceras Zone, from the presence of a number of broad-skulled hornless rhinoceroses.

Lower.—Of undoubted Lower Pliocene age is the recently discovered Snake River deposit of western Nebraska, the Neotragocerus Zone, and the Virgin Valley and Thousand Creek of Nevada. The arrival at this time of true Old World tragocerine and hippotragine antelopes from Asia, as identified by Matthew and Merriam, is one of the most noteworthy discoveries in recent paleontology. These antelopes may prove to demarkate our Lower Pliocene, in which case the Republican River will be pushed back into the close of th Miocene because it certainly does not contain these Old World forms.

The Lower Pliocene, or Plaisancian, of Europe is represented by

PRELIMINARY CORRELATION

		EUROPE	ASIA	NORTH AMERICA
PLIOCENE	Upper	Sicilian	Siwaliks	"Loup River"
	Middle	Astian	Siwaliks	Blanco
	Lower	Plaisancian	Siwaliks	Thousand Creek Rattlesnake and Republican River
MIOCENE	Upper	Pontian	Manchhar	"Loup Fork" Madison Valley Clarendon
	Middle	Vindobonian	Manchhar	Deep River Pawnee Buttes Mascall
	Lower	Burdigalian		Arikaree "Upper Harrison" Rosebud
			AFRICA	
OLIGOCENE	Upper	Aquitanian		Harrison (Lower) John Day White River(Upper)
	Middle	Stampian		White River (Middle) Brulé Clays
	Lower	Sannoisian	Fayûm	White River (Base) Cypress Hills Pipestone Creek Chadron
EOCENE	Upper	Ludian	Fayûm	Uinta (Upper and Middle) Washakie (Upper)
	Middle	Bartonian		Uinta (Lower) Washakie (Lower) Bridger (Upper)
		Lutetian		Bridger (Lower) Huerfano (Upper)
		Upper Ypresian		Bridger (Lower) Huerfano (Upper) Green River
	Lower	Lower Ypresian		Huerfano (Lower) Wind River Wasatch (Upper)
		Sparnacian (Upper Landenian of Belgium)		Wasatch (Lower)
		Upper Thanetian (=Cernaysian) (Lower Landenian of Belgium)		Torrejon Fort Union
	Basal	Lower Thanetian		Puerco Fort Union
CRETACEOUS	Uppermost	Danian = Maestrichtian (Terrestrial) (Marine)		Hell Creek

the mammalian life of Casino, which is very sharply demarkated from that of Pikermi.

Middle.—The Astian, or Middle Pliocene, life of France, typified at Roussillon and Montpellier, is broadly comparable with the Blanco of Texas, where we enter the sixth faunal phase, marked by the invasion of South American armored edentates, or glyptodonts, into the southern United States. These deposits are accordingly known as the Glyptotherium Zone. They mark a great advance upon those of the Republican River.

Upper.—The Upper Pliocene, or Sicilian, stage of Europe, typified by the Val d'Arno fauna of northern Italy, is hardly comparable with any American horizon. We are here on the border-line between Pliocene and Pleistocene, and a great deal of research is still needed. The Peace Creek deposits of Florida (Dall) may help us because here we discover an Equus and an Elephas Zone overlaid by marine Upper Pliocene molluscs. Rather primitive forms of Equus and Elephas are also characteristic new arrivals of the Upper Pliocene, or Sicilian, stage of Europe. The same doubt applies to the little-known "Loup River" of Nebraska, in which *Equus* and *Elephas* were discovered by Leidy many years ago.

PLEISTOCENE

Perhaps the most striking determinations which await the mammalian palaeontologist are those which close comparison of the Pleistocene stages in the New and Old Worlds will afford. In Europe we have four great series of correlation data, namely:

The geologic succession of the glacial depositions;

The faunal succession especially among the higher mammals;

The evolution of stone implements of human manufacture;

Stages in the skeletal evolution of man.

In America the two kinds of data connected with the evolution of man are entirely wanting, and we are thrown back on the geologic and the faunistic divisions; consequently close comparison in these two lines of evidence common to both countries is all the more necessary. In Europe it is possible to distinguish four grand faunistic phases, namely:

The first early Pleistocene fauna, Eolithic Stage of culture;

Second or mid-Pleistocene fauna, Eolithic and early Paleolithic Stages;

Third or Upper Pleistocene fauna, late Paleolithic Stage;

Fourth, post-Glacial fauna, Neolithic Stage.

From close study of the Pleistocene life of North America there is promise of correlation with Europe through identification of American with European glacial and interglacial periods, through the discovery and identification of interglacial faunas, as in the Aftonian and Toronto deposits, through the careful recording of the time of extinction of native types and of the time of arrival of new types to demarkate our Pleistocene also into great successive life-zones.

The chief progress made thus far (1909) is that we begin to recognize the following divisions of American life:

Early and mid-Pleistocene life of the plains, *Equus* Zone;

Mid-Pleistocene life of the forested regions, *Megalonyx* Zone;

Life of the maximum cold period, *Ovibos* Zone;

Life of post-Glacial times, Zones of *Cervus* and *Homo*.

Especially interesting is the coincidence of the maximum cold period, or *Ovibos*, Musk Sheep Zone of America, with the maximum cold period, or *Elephas primigenius, Rangifer tarandus* Zone of Europe.

It is obvious that we should never expect to discover as clear demarkation of the life-zones in America as in Europe because of the vast refuge areas of the mammals in the south. In Europe the glacial advances are sharply punctuated by the appearance and disappearance of species. In America apparently such appearances and disappearances are gradual.

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